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INDOOR POSITIONING TECHNOLOGIES FOR INDUSTRIAL AUTONOMOUS HEAVY-DUTY VEHICLE APPLICATIONS

Bachelor thesis of science

Supervisor: Jose Martinez Lastra

ABSTRACT

ALEKSI SAVELIUS: Indoor positioning technologies for industrial heavy-duty vehicle application.

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The importance of autonomous navigation has gained attention of the research and industrial community, mainly for brining self-driving vehicles to the large audience. However, this importance is not new within the industrial sector, and special for those dedicate to indoor logistics of heavy and large items. As a consequence, the industrial sector is benefiting from the technologies and methods developed for the general audience and bring this area to a new level of development.

This work firstly presents a survey of the most relevant indoor positioning technologies and methods from the heavy-duty industrial applications viewpoint. Finally, a few commercial autonomous heavy-duty vehicles and their positioning methods are presented.

CONTENTS

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1 INTRODUCTION

Indoor positioning is becoming more important through industrial robotics and mobile robots. Mobile devices are given more and more challenging tasks to achieve and so on their requirements in accuracy and speed are becoming higher. Task are basically to go from a point A to a point B, through some a specific route and without hitting any objects. In time, tasks have become more varied and harder for the technologies.

This paper is written as a bachelor thesis of science for the laboratory of factory automation and industrial informatics at Tampere University of technology. This papers goal is to give readers general view of this day's main indoor positioning technologies and how they could be exploited in indoor heavy-duty vehicle applications. This thesis will look into few basic technologies in indoor positioning and the basics how the technologies work in general level. The thesis won't go through deeply positioning methods and technologies. Also positioning and navigation are very close to each other and some of the positioning methods are more or less navigation methods. Still this papers main subject is to explain how these technologies and methods give to a vehicle position information.

The thesis is in five sections. In first chapters the thesis will give to the reader general view of requirements that autonomous vehicles have and what kind of data is needed to become autonomous. It will give point of view from differences between indoor and outdoor positioning, but still the thesis will focus to technologies that are used indoors. Technologies as global positioning system (GPS) is not handled in this thesis.

A section three will go true positioning and navigation methods. The navigation methods can be separated roughly in three category: map based, mapping methods and a guidance methods. In map-based methods vehicle uses already known map and it will always try to find itself somehow from the map by using technologies given to it. The mapping methods create own map to themselves and they will remap it every time the map changes. Guidance methods tells to the automated vehicle that is it on the route or not. The chapter will tell the general ideas of the technologies and it will describe how they are used in industrial applications.

The fourth section will manage more applications that are commercial applications. The chapter will introduce few applications and then tell more about the applications' navigation and positioning methods. This chapter's main point is to give to the reader a little idea that what kind of autonomous applications are already as commercial products.

The last and the fifth section will handle results of the thesis. It will look true methods and technologies that would be the best to integrate heavy-duty indoor vehicles. Most of the ideas are the writers own ideas and there could be more and better solutions out there. The results are conclusions from the data that is handled in this thesis.

2 INDUSTRIAL AUTONOMOUS VEHICLES

These days' modern autonomous vehicles and automated guided vehicles (AGV) can operate at a factory floor, on outdoor off-road trails or even on an office floor. A terrain and surroundings determine a structure of a vehicle's platform. For example, an off-road truck needs bigger wheels than factory's an indoor forklift. A vehicle's purpose and tasks define rest of the vehicle's structure. Does it need a forklift or big roof's surface with lot of lift power?

Few things make a vehicle autonomous. When an operating person is removed from the vehicle, the vehicle needs every instinct that the operator used while using the vehicle. Most important abilities come from different type of sensors. The vehicle needs to have a knowledge of its own location and position. It needs to know its own speed and the direction of the movement. Same information has to have from tools that the vehicle is using. It needs to know also the positions and movements of other objects and vehicles around it. The vehicle uses all those data to make decisions in its control centre. After this comes higher-level operating systems (like manufacturing execution system [MES] and enterprise resource planning [ERP]). With all of this information, the vehicle can be called more or less autonomous.

2.1 Indoor vehicles

Indoor vehicles operate mainly on a factory floor and in a warehouse. Main tasks that they have are moving and lifting objects like tools, parts and material. The moveable part defines the vehicles structure and the tools that it is using.

The surface where the vehicles are operating is mainly smooth and in horizontal level. Mostly the indoor vehicles use smaller wheels to move and have no suspension when the floor surface is smooth. Vehicles that need bigger accuracy have no suspension in the base. The suspension in wheels makes extra movement for the whole structure.

On the factory and warehouse floors, there are many other objects than the vehicles as like shelving units, machines, human workers and other vehicles. Autonomous indoor vehicle has bigger need of accuracy than autonomous outdoor vehicles because of the tight working environment.

2.2 Outdoor vehicles

Outdoor vehicles may operate outside factories and warehouses and even in off road trails. Some vehicles can operate both in outdoor and indoor rooms. Vehicles tasks are more or less moving objects, products or materials when moving outdoor spaces.

An outdoor surface is usually concrete or asphalt and therefore more rough than the indoor floors and that is why the outdoor vehicles have bigger wheels. They also use suspension, if big accuracy is not needed.

The outdoor vehicles can be for example regular trucks or shipyard container trucks. The shipyard container trucks move containers between ships and a container yard [1]. They have own big bodies and on their terrains have same size or bigger objects to dodge. The needed accuracy during a transportation is smaller than indoor vehicles, because the objects are bigger and the environment is more open space around the container trucks.

3 INDOOR POSITIONING METHODS AND TECHNOLOGIES

In this section of the paper, the thesis will go through few positioning and guidance technologies. Some of the methods are close to navigation methods, but same time they do positioning as well. Those will give general view that what kind of possibilities are to make a vehicle or a robot more autonomous.

An automated guided vehicle (AGV) needs to have information of its own speed, a direction of the movement, an own location and other objects' positions. A vehicle can get almost every needed data from some positioning technology. The position information helps the vehicle to complete movement tasks through a factory floor. Without the positioning information vehicles are quite blind or they won't have an ability to move right direction. The position information can be from nearby objects and general knowledge of the position inside a building or on a factory floor.

Indoor positioning systems (IPS) are used in indoor navigating applications and the IPS forms from a positioning technology and a higher system data processing. There are few main technologies that are used in the indoor positioning. Some technologies are based on fixed radars or beacons that are not located in a vehicle. Other technologies are dependent on different markers or colours (like tapes) that are integrated in floors or walls. When it comes to dodging unknown objects like humans that change their locations, vehicles need to have own sensors and beacons that scan continuously a vehicle's surroundings.

There are more or less challenges in the positioning depending the positioning technologies. When vehicles become autonomous they need to be free from external wires. That'll bring all challenges that wireless signals have. Some signals have bad ability to permeate though materials like metal and concreate. They need also more capacity when the signal is needed in further distance. Beacons and radars can get confused from irregular floors or unwanted reflection surfaces. When used several technologies simultaneously, the possibility of false position information is lower.

3.1 Inductive guidance

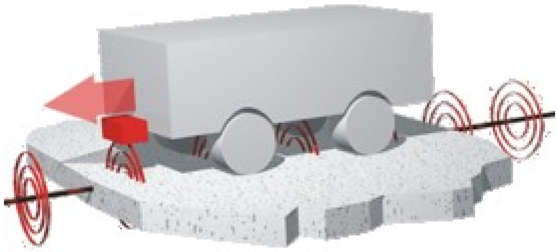

Figure 1: Wire guidance [2]

An inductive guidance won't give an exact position data to an AGV, but it will give a position where a used route is located. Like its name, it will guide the AGV. The inductive guidance is based on an electromagnetic induction. The electromagnetic induction is a basic physical phenomenon where a changing magnetic field induced voltage to a coil. Same effect is used in electric motors. Changing magnetic field emits voltage to a coil as stated in equation (1). Where ε is voltage, N is number of coils rounds, A is the coils' area, B is change of the magnetic flux. [3]

$$\varepsilon = -NA\frac{t}{dt}B \qquad (1)$$

Equation 1: Voltage generated by changing magnetic field in coil.

The inductive guidance as a wire guidance is used in industrial applications and it's implemented with developed with the electromagnetic induction. Applications have own coils that senses a metal path wire that is integrated into a factory floor or into a general path. The path wires is conducted small amount of voltage that the vehicle detects. The vehicle drives above installed path wires and the vehicle's own coil recognizes a emitting voltage from wires. The detecting sensors are mounted front and back of the vehicle, so it can detect its own position depending on the path wire. Similar guiding technique is a tape guidance. Where a vehicle reads a tape from a factory floor and makes correction movements if the sensor is going to go over the tape. [4]

The path wires and the inductive guidance is effective way to get a route's position information when vehicles use same paths and don't face too many conflict situations. Now a day, wired floor tell to a vehicle only that, that it's on its own path but won't tell witch path. Automated guided vehicles can't operate only with inductive guidance. So, AGV vehicles need additional positioning technologies besides inductive guidance. Wire guidance only tells AGV where is the main paths to use. An inductive sensor readings are also accurate so vehicles can operate in tight spaces. Path wire integrations to floors is expensive afterwards in factory. Cheaper application from path wire system is magnetic or conductive tape. Those are easier to install and repair when needed. Factory layout changes are also easier to achieve. [4, 5]

For example, JBTC has a fork lift application that is meant to operate between narrow aisles. It's guided by several sensors and one is wire guidance. The accuracy that the fork lift needs between warehouse shelfs is achieved by the wire guidance. [2]

3.2 Magnetic Spot Guidance

A magnetic spot guidance (MSG) is used similarly as the inductive wire guidance. In one application, the main difference is in the hardware, in factory floor is integrated magnet spots in lines instead of guide wire. In the magnetic spot guidance an AGV has only a position data from a path like in the inductive guidance. Also, the applications where MSG is used are lot of similar than in inductive guidance. [5]

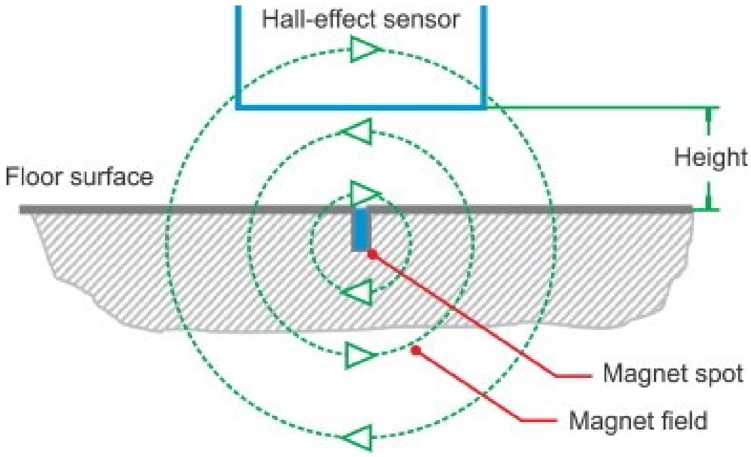

Figure 2: ***Hall-effect sensor above magnet spot*** [5]

The magnetic spot guidance is based on a hall-effect. The Hall-effect is a physical effect. When a conductive plate (Hall Element) is brought to a magnetic flied, magnetic forces draw electrons and protons to different side of the plate. This produces a voltage difference between the plate's sides. A Hall-effect sensor is one way of measuring magnetic flux by measuring the voltage difference in the plate. The sensors are used also in motors by measuring rotation speeds from gears. [7, 8]

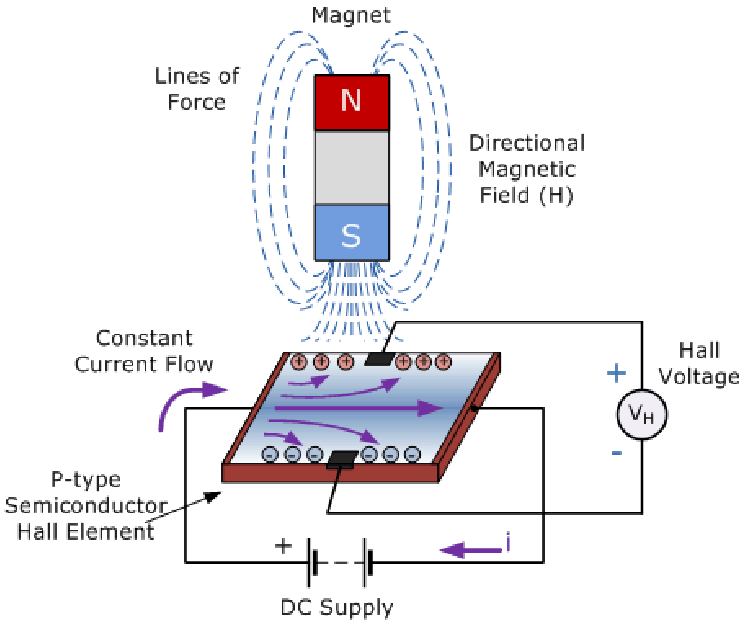

Figure 3: ***Hall-effect*** [7]

Magnet spots mark paths in a factory floor. The magnet spots can be used also as coordinate points. AGVs read the magnet spots with the Hall-effect sensors. The Hall-effect sensors calculate maximum density of a magnetic flux from floor magnet spots. Then it gets a three-dimensional direction where the floor magnet spot is located. The vehicle is right above the magnet spot, when the main direction is straight down. Magnet spots forms web through a factory or a warehouse floor and vehicles navigate through it using magnet spots as coordinates. The magnet spots can be used only as paths through a factory floor. [5]

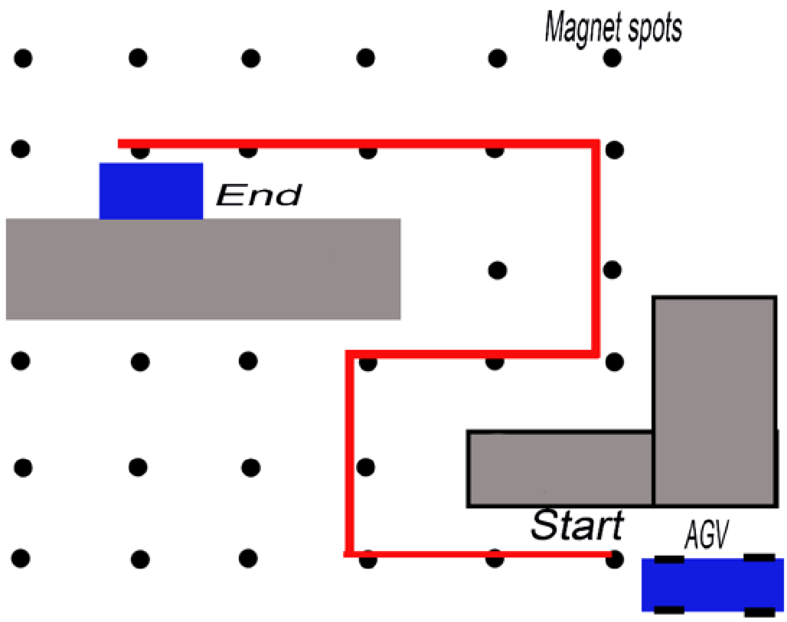

Figure 4: ***Magnet spots layout and navigation true factory floor.***

In figure 4 magnet spots form XY-coordinate system. An AGV can navigate through factory layout when fixed objects' locations are known. The AGV gets route to the goal from a higher system so the AGV can identify turning points and turning directions.

The MSG guiding option is better when it becomes to repairing a navigation system or changing the layout of a factory floor. It is also easier and cheaper to install. However, the magnet fluxes can be easily distracted by others magnetic fluxes. Also, a big continuous magnetic fields may distract other equipment that are sensitive for magnets. [5]

3.3 Ultra wideband

An ultra-wideband (UWB) is based on electromagnetic waves that are sent very fast pulses and big bandwidth. For example UWB can be used in range between 3.1 and 10.6 GHz. The UWB is used in radar, security and medical applications. [4]

As in a positioning technique generally the UWB uses two or more fixed beacons as transmitters that are located in known locations on a factory floor forming a sensor network. Navigating vehicles use mobile devices that contains a UWB receiver and sometimes a UWB transmitter combination (in multi communication applications). Systems calculates vehicles distance from receiving identified signal. With two distances, system can calculate location using triangulation method [14]. Also the global positioning system (GPS) uses same triangulation method. In open spaces with two beacons system can get even two location results if the beacons are not located corners and the measurement is taken in 2D. The corners drop out the second position result. The results of locations drops down to one with several beacons. For example, in figure 5 three anchors (beacons) have three different distances and with them system can calculate the target position. [4]

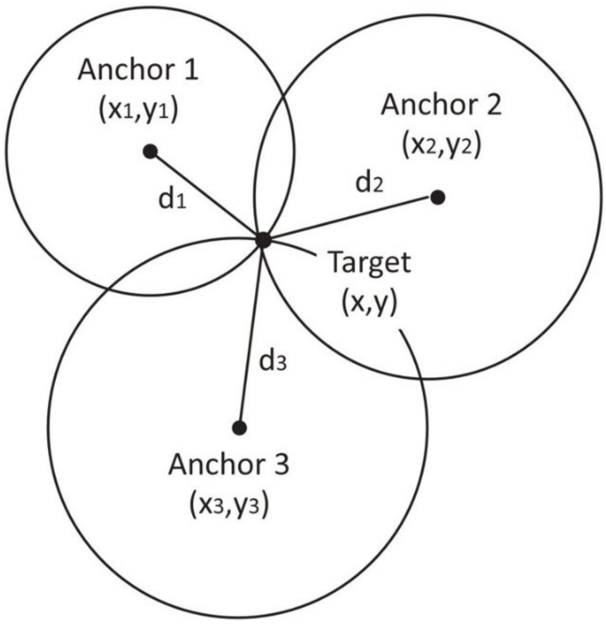

Figure 5: ***UWB triangulation method*** [14]

Ramon F Brena and al [4] presents in their article that there are two measure that can be used in UWB positioning. Measures determine the distance between the target and a reference point (as a beacon). First, is a Time of Arrival (ToA) and second is a Time Difference of arrival (TDoA). In ToA system calculates mobile devices position from flight time from transmitting beacon to mobile device and from mobile device to receiver beacon. In TDoA mobile vehicle calculates its location by the time difference it gets from beacon signals. [4]

Example of a UWB application is an Ubisense real-time location system. It uses in mobile devises as called Ubitags that include a transceiver and a UWB transmitter. Tags are small and they are individual so every autonomous vehicle or mobile device can be recognized as separate. The tags also send normal 2.4 GHz radio signal for communicate with each other. The system has fixed Ubisensors as beacons. [4]

The system uses both the TDoA and the ToA to calculate objects' locations. The system can calculate mobile devices 3D position with only two beacon sensors by using angel of arrival (AoA) method. The sensors receive UWB signals and they calculate the angle of an arriving signal. [4]

The UWB's advantages as an indoor positioning technology are precision of time-of-flight, having no problems with multipath and low requirements of power. It is also affordable to install comparing to other fixed and built in applications as the magnet spot guidance. The UWB is also one of the most accurate methods. The Ubisense applications authors claim that the Ubisense can achieve even 15 cm accuracy. [4]

3.4 Radio Frequency Identification

A radio frequency identification (RFID) uses a radio frequency to transmit specific data from a RFID tag to a RFID reader. The tags have their own IDs and when they pass by the RFID reader, the tag emits personal data to the reader. The RFID technology is used in many applications where several IDs is needed. [4]

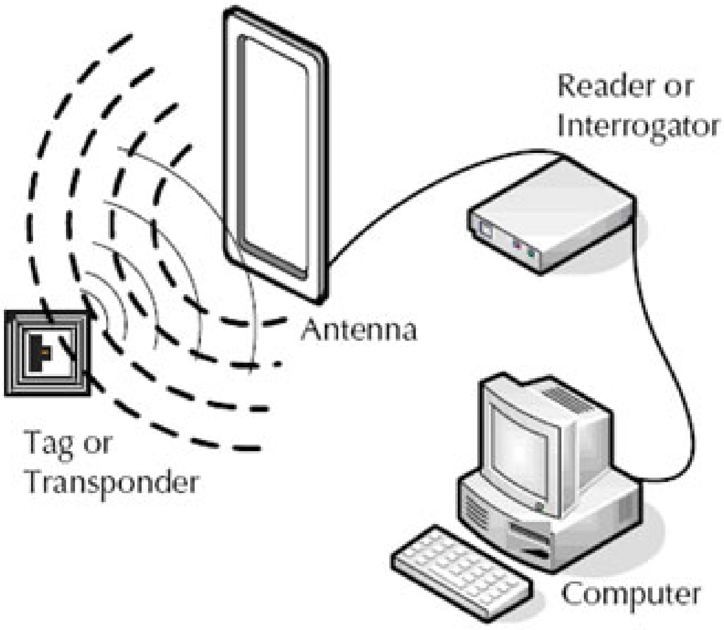

Figure 6: ***RFID tag and reader*** [15]

The RFID tags act as an antenna and they are able to emit signals with information. The tags can be passive or active. As “passive” tags, they emit signal only when they detect a reader’s signal. The passive tags also can power up themselves from the readers signal. “Active” tags have own a power supply and they send periodically their own ID signal. The tags can be “semi passive”. Then they use own power supply and send signal only when the reader’s signal is noticed. [4]

The RFID is used in applications as a department store security, logistics and medical equipment. In indoor position techniques, the RFID is used in identification of vehicles or mobile robots or locations. The RFID is used as X,Y-coordination, where the tags are as reference or coordinate points on a factory floor and an AGV has the RFID reader. Like this the RFID tag informs to the AGV the AGV’s position, when the AGV drives over the tag and reads the tag’s coordination information. With only RFID tags an AGV can have problems with navigation, but when added another positioning method (as laser or natural navigation) it could be autonomous while moving through factory floor and autonomous navigation can be possible. [4]

For example, a Ferrometal RFID-Kanban uses the RFID tags when supplying small metal parts like screws to its customers. The Ferrometal supplies reader shelves to a customer and small metal boxes with RFID tags. Every box has own information of a product and amount of the product in them. When the tag box is empty, a worker moves the box to an empty box area. Same time the box goes through a RFID reader and the reader send information to higher level system. The Ferrometal gets information from the system, that how much products the need to supply in next cargo. [16]

3.5 Natural navigation

A natural navigation (NN) is based basically memorizing already seen places. It can be applied to navigation system, but it is also used as a positioning method. With visual footage or laser or sonar scanned surroundings system can form own general knowledge of fixed land marks. Land marks are used as mapping reference points and they can be recognized after they are analysed and added to a formed map. A vehicles can move autonomously true a factor and same time make own map of the factory's layout. Natural navigations give to the AGVs total freedom from reflectors or markers like magnetic spots. Navigating with Qr-code tags or an optical navigation or the magnet spot navigation can be natural navigation when they base certain kind of land markers. They still are dependent built-in markers or reflectors. [10, 13, 17]

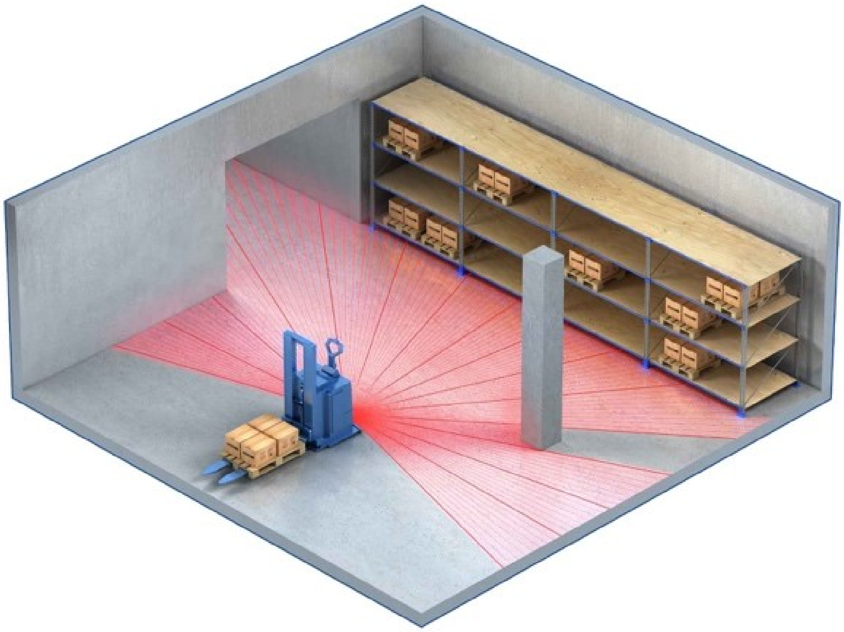

Figure 7: Autonomous forklift using laser scanning as natural navigation. [18]

An AGV needs knowledge of its own speed, direction of the speed and scanned images from surroundings. With all that information the autonomous vehicle can build own map of places it's been before. The vehicles operators can add afterwards accurate reference points to vehicles own map, so they can be used references when making transport/movement orders. With a ready map, the AGV can compare its own measurements from surroundings to locations that is found in the ready map. This way the AGV can recognise its own position from the map. [5, 10, 17]

Figure 8: Distance data gathered by KUKAs navigation solution [19]

The natural navigation that work without built-in markers are affordable comparing to those that need fixed markers. Continuous mapping is not affected by factory layout chances. When vehicle notices change in its own map it will do re-mapping for that specific area. Vehicle can skip re-mapping if it's faced human or another autonomous vehicle. Then it will recognize the movement of the other object and skip the re-mapping and just dodge the other object. Still if the other vehicle or human is staying still it may remap that certain spot but next time the vehicle passes the same spot it will remap it again. In most applications, several vehicles communicate with each other as they use same map and when vehicle need to do re-mapping they modify the same map. Then every vehicle in whole system will have same information of other moving object and changes of the built-in layout. [10, 17]

3.5.1 Laser measurement

A laser measurement is based on laser beam. A laser sensor is sending laser beams and a scanner reads the reflected laser beams. When the speed of light is known, the laser sensor can calculate a distance where the beam reflected. The math in the calculation is based Time-Of-Flight (TOF) method (explained in equation (2))[9]. The laser sensor sends vertical beams, so it can get several distances form one sector. The distance data is sent to a AGV's control board, that creates information from the surroundings of the AGV. [9, 10]

The laser measurement gives distance information of other objects. With laser sensors the vehicle can be more independent and autonomous comparing to the wire or magnet guidance. The vehicle is not dependent to any other fixed station or technologies. The vehicle has data about its own surrounding and it can make conclusion where it can move and where not. Problems come when the vehicle needs to know where it is located generally on factory floor. It may move through whole factory and scan the factory's layout to itself and then make conclusion where it's located. Here is when the NN method comes in. [9, 10]

$$d = t * c \tag{2}$$

Time of flight (TOF) principle: d = distance, t = time of flight, c = speed of light.

Usually laser sensors are located on top of vehicles when scanning general surroundings. They can also be located to the corners of a vehicle and near to a floor's surface so the vehicle may get readings that are more accurate from its drive path. A laser sensor can get 360-degree data when the sensor is spinning. Sensor updates every sectors distance data in every lap. Distance data is continuous when the spinning speed is fast enough. [1]

Navigating with lasers is effective way to get distance data. These day sensors use quite narrow beam. In need of wider data area, the laser is needed to point in several directions or need to mount several sensors. Also, when the measuring distance crows the accuracy error increases.

A measuring with a laser sensor is accurate and fast. The accuracy of measurement suffer when a measurement point is getting further so the laser measurement is most efficient when measuring close distance. When a laser is used public or general territorie (for example indoors), the laser power is needed kept low. [9-11]

One commercial laser scanner product is a light detection and ranging sensor (LIDAR). The LIDAR is sensor that includes a laser diode, a laser receiver and a scanning mechanism. It is usually mounted on top or in skirt of a vehicles and it is scanning certain sector or 360 degrees with rotating prism. It measures distances from only the specific sector by using TOF principle.

Figure 9: ***Sick 2D LIDAR sensors***

3.5.2 Visual recognition

A visual recognition is based in computer vision and analysing camera footage. This positioning method is basically natural navigation with camera view. Land marks and reference points are as important as in other natural navigation styles.

There are several ways to process image in visual navigation, but one way is to compare already known CAD (Computer-aided design) models to the navigation footage. In this process a system has a library of already known objects that a vehicle may face during its drive. Continuously the AGV scans surroundings with camera. When vehicle gets matching result between a CAD library model and the camera footage it may use the CAD model as map. Vehicle can recognize possible locations through the CAD model and steer its own movement to possible routes without hitting obstacles found in the model. Same time, when the AGV recognises the matching result that might be a marker point in a map. Then the AGV can locate its position from a ready map. This is also based more on map based navigation. [12, 13]

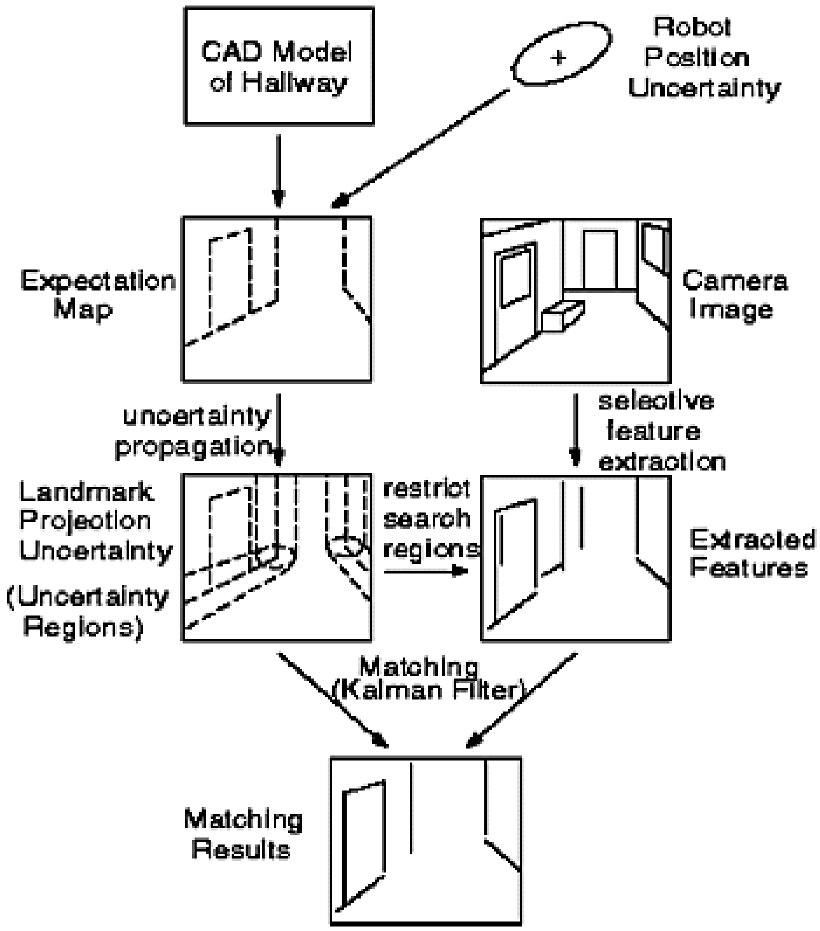

Figure 10: Visual navigation footage process [12]

The visual recognition is used more in mobile robot applications that may move more in quickly changing terrains and also then when the robot needs more freedom from surroundings. Still the technique used in figure 6 is dependent of scale of the CAD library and a long analysing slows down whole the positioning and the navigation process. [12]

Visual navigation becomes very handy when robot needs more freedom from the navigation systems and same time becomes more autonomous. Navigation's accuracy is not in the same level than with the laser sensors. Moving in open halls with visual navigation works well, but when needed bigger accuracy system needs more sensors than the camera footage. For example, situation when autonomous vehicle needs to get on some object from loading station. Then it may approach the station with visual information, but in connecting to the station the vehicle needs more accurate sensors like wire or magnet spot guidance. Also visual navigation system is affordable to install and it is not affected by factory layout changes making it flexible system.

3.6 General view

Previous positioning methods were only some of these days' methods that is used to get positioning data for autonomous vehicles like AGVs and mobile robots. In this chapter, this paper evaluates strengths and weaknesses of the technologies. However, some of the methods can't be compared with each other because their goal of measurement can be different. Beside these methods there are more different technologies used in positioning like Bluetooth and Global Positioning system (GPS) that uses public satellites. In table 1 is gathered data from chapters 4 methods. In the table symbols are H = high and L = low. A coverage gives perspective of the area that method can cover in use.

Technology	Accuracy	Install, maintain cost	Cost in use	Coverage	Strengths	Weaknesses
Inductive Guidance	1-10cm	H	L	Building	High precision	Not transforma-ble, Only path guidance
Magnetic Spot Guid-ance	-	H	L	Building	High precision, Modular routes	High cost
Natural navi-gation with la-ser sensors	(1cm-5cm)	L	L	-	High precision	Sensitive to other reflections
Natural navi-gation with visual sensors	1cm-100cm	L	L	-	Low cost	Sensitive to light
UWB	15 cm	H	H	Building	High precision	High cost
RFID	1-5 m	H	L	Room/door gate	Low cost	Low precision

Table 1: Positioning technologies' and methods' strengths and weaknesses

In accuracy methods give difference between the measured distance and the exact position. In accuracy best performance gives the inductive, the magnet and the natural navigation with laser sensors. The accuracy information changes between different applications in magnet spot guidance. In the magnet spot guidance the accuracy is effected by components used in the application and the reading height shown in figure 3.

The natural navigation with laser sensors and visual sensors is best in install and usage prices. These methods have hard time to work autonomously by itself but still doable. In coverage best is to head positioning method for whole building. The natural navigation with laser sensors and visual sensors are not dependent on fixed stations, so the coverage does not affect them.

Here these technologies and methods can be roughly spliced in two. Methods that guide vehicle only to stay on route and methods that give you data of vehicles location. Inductive wire and magnet spot guidance goes to the first part and almost rest of the methods to the second part. Still total autonomous vehicles need both sides to work. Some second part methods can do all for moving autonomously but still some methods can complete same tasks better and more accurate.

Every method has its own strengths, but also some weaknesses. If the technologies are used in areas where they are good at and that way vehicles' positioning and navigating could be optimized with several technologies. For example, an AGV may use the UWB for general positioning with already installed map and still use natural navigation with lasers to do re-mapping and object avoidance.

4 AUTONOMOUS INDOOR HEAVY-DUTY VEHICLES

Heavy-duty vehicles can be working in indoors, outdoors or both. They are normally categorized as heavy-duty when they need to lift or transport bigger objects than normal vehicles should. For example, chapter's 2.2 container trucks are classed as heavy-duty vehicles.

When there is needed bigger forces a structure of the vehicles becomes bigger and movement speeds drop significantly. Big forces require more power from the system and then the system becomes slower. Even if the speeds could get faster, it is kept down for safety reasons. In indoors the vehicles size is tried keep in minimum and action speeds of the vehicles fast as possible but still inside safety limits. Movable objects and the vehicles size and weights put limits for the action speeds.

This chapter looks into few commercial applications that are more or less classified as heavy-duty vehicles and more or less autonomous their own way. Same time this part will handle positioning technologies that are used in the applications.

4.1 Commercial applications

Figure 11: ***KUKA OmniMove*** [20]

First applications are a KUKA's OmniMove models. They are classified as mobile platforms and the strongest model can lift weight up to 90 tons. The OmniMove is powered by electric batteries and it moves with Mecanum wheels, even if the name is OmniMove. The Mecanum wheels give to the vehicle 360-degree freedom of movement just by changing a turning speed comparing to other wheels. The vehicle can also move to any direction in any position compared to the direction of the movement. The movement is called Omni-directional movement. The OmniMove can be connected to other OmniMove mobile platforms forming one bigger platform, so they can lift heavier and larger objects. For example, three OmniMoves connected together can lift Falcon 2000 airplane shell. A fleet management controls multi AGV platforms tasks and takes care of multi-platform connections. When the AGV platforms are connected together, there is an one master platform and the rest of the platforms are the master platform's units. The master platform gets tasks and does actions. The unit platforms act as part of the master platform. [20,21]

The second application that this part looks into is Omron's LD mobile robots. They are not classified as heavy-duty vehicle, because the maximum load is only up to 130 kg with the strongest model LD130-CT, same time the maximum speed drops from the fastest model LD-60 1.8 m/s to 0.8 m/s with the LD130-CT. They are medium sized indoor robots and manly programmed to transfer unique carts by lifting the carts from bottom. The robots use roof as lifting surface. They move by six wheels, two of them control speed and direction and rest of them carries the weight. [22]

Figure 12: Omron LD-60/90 (left), Scheuerle 6 line SPMT (right) [23,24]

The third application is Scheuerle's Self-Propelled Modular Transporter (SPMT). The SPMT is classified as heavy-duty vehicle with 216 tons pay load in 6 line SPMT model. The SPMT can have from four to six lines of wheel pairs. Each wheel pair can be controlled independently and that gives a possibility to move any direction with any position compared to the direction of the movement like in the OmniMove application. All models are meant to be used at outdoor locations, but doesn't take away possibility to use in indoors. SPMT models are classified as mobile platforms that mainly transfer object on top of them, but same time they are also only 1.5 m tall. These platforms are mainly meant to carry big objects as large ship bodies. This is why the SPMT is only partly autonomous and it does not use any positioning methods. The SPMT is meant to move so large objects, there is no need to make it totally autonomous. [25]

Figure 13: ***Solving Film Mover carrying 100T transformer*** [26]

Next applications are Solving's AGV fork lifters, wheeled movers and air film movers. Both movers are mobile platforms. The fork lift has ability to 160 tons lift force and it is meant to do recurrent tasks and therefore it is totally autonomous. Wheeled mover moves with wheels and has ability to 100 tons lift force. The wheeled movers and the film movers are classified as mobile platforms. The film mover gets speed and direction from control wheels, but lift force from air pillow with compressed air. The film mover has lift force up to 300 tons and it is only 40-50 cm tall platform. The film mover control wheels also turn 360 degrees and gives to the mover same freedom of movement as the Omni-Move platform has. [27]

Figure 14: ***Solving Fork lift AGV [27]***

4.2 Applications' sensors and positioning

From application that chapter 4.1 introduced, there is only few that are fully autonomous. They are Omron's LD, Solving's AGV fork lift and Kuka's OmniMove. Partly autonomous are Scheuerle's SPMT and Solving's wheeled movers. This part will handle the applications' sensors and their positioning methods.

The Solving's film mover is only classified as a heavy-duty vehicle and works with a remote controller, however the film mover has good possibilities to become a totally autonomous vehicle. The only problem with the film mover is that the film mover gets its compressed air from general compressed air network and needs to be connected to the compressed air network while lifting objects and while moving the objects. The problem could be solved with an integrated compressor, but the size of the compressor would not be handy compared the size of the film mover. [27]

Omron's LD mobile robots use mainly laser sensors in its front and sides. The side sensors scan also the rear areas of the robot. Also for scanning the rear area the LD uses a sonar radar. All these sensors collect mainly distance data from surroundings and detect obstacles. With lasers the LD creates its own map using NN method. There is also a possibility to apply complete map to the higher control system (like the fleet management system). The LD uses also the patented Acuity method with a light sensor. In the Acuity method, the system detects and creates map from lights at the ceiling and compares the light map to the created or already given floor map. This helps the LD to move across open areas when there is no possibility to get distance data from surrounding objects. The LD mobile robot has also an option to use inductive guidance with magnetic tape. [22]

The Kuka's OmniMove uses a Kuka's own navigation solution. This solutions uses mainly laser sensors (like in figure 9) for scanning surroundings and a wheel encoder to measure the Mecanum wheels rotation speeds and directions. The laser sensors are located close to floor level so they can notice low obstacles. The navigation solution is based on NN method and it gathers a distance data from laser sensors. The laser sensors supports also a collision avoidance and a collision free path planning. Kuka's navigation solution supports alternative route planning when a main planned route is not available. Kuka claims that the OmniMove has a positioning accuracy up to +/- 1mm. [19]

A fleet management is so called a higher system when a factory or a warehouse needs to control several AGVs simultaneously. The fleet management system takes care of for example factories' a traffic control, a collision notifications, alternative path planning, mapping, a task delegation and so one. The system controls also multi AGV tasks where several AGVs are used to do one task simultaneously as one AGV where several vehicles are connected together or separately moving as one formation. The positioning and navigation systems importance rises up, when AGVs are performing one task in formation.

The companies as Kuka and Omron provide a fleet management system to their AGV applications. The OmniMove and Scheuerle’s SPMT supports the multi-platform tasks where several units are connected together. For example in this way Scheuerle SPMT fleet is used to transport full size ship frames.

5 CONCLUSION

In this chapter I will handle the positioning technologies that are introduced in chapter 4. The goal is to get conclusion that what a technology/technologies would be best to apply in autonomous indoor heavy-duty vehicle. I'm going to go through some situations that AGVs could face when they are operating tasks on a factory or a warehouse floor. I base my opinions on previous chapters in this thesis. In cart 2 markings mean: x = can perform in the situation, -/- = can perform somehow in the situation, - = can't perform in the situation.

	Positioning technologies/methods			
			Fixed technologies	
Situation	NN with laser/optical sensors	UWB	Inductive/magnetic guidance	RFID
Factory floor lay-out changes	X	X	-	-/-
Collision avoid-ance	x	-	-	-
Open floor man-agement	-	-/-	x	x
Variety of tasks	X	X	-	-
Frequency of same tasks	X	X	X	X
Communication between AGV	-	X	-	-

Table 2: Positioning technologies' and methods' performances in different types of situations.

First I will look into situation where a factory's floor's layout changes and how the positioning technologies can handle them. The layout changes are made when a factory needs to apply a new work station and a new machines. This won't happen every week, but when it does the positioning method in use needs to adjust to the change. Some methods won't adjust as easily as others. Guidance methods as an inductive guidance, a magnet spot and a RFID positioning are based on fixed hardware. Layout changes comes expensive on these methods, when same time the hardware needs to be also modified. In the magnet spot positioning, magnets are mounted in a floor and in the inductive guidance has a metal wire mounted in the floor. The inductive guidance can be implemented with magnetic tape, then the layout change is easier. Also the RFID route modifications are easier when RFID tags are small and easily removable. An ultra-wideband method is attached on its beacons. So the UWB's routes are as easy modified as a movement of the beacons. A natural navigation with laser or optical sensors is not attached to any fixed station, so the NN method is not affected at all of the floor layout changes. Although the floor layout change will affect the NN's route control.

Maybe the most important situation as a safety feature is a collision avoidance. Every automated vehicle should have this feature. Without this an AGV should not be moving autonomously. In table 2, only the NN method with laser or optical sensors has total collision avoidance. A laser and optical sensor get accurate measurement data from surroundings that an AGV can detect incoming obstacles and humans. Every other method in table 2 needs to be applied some a collision avoidance technology to be used total autonomous vehicle in a factory or a warehouse environment. A good collision avoidance can be implemented with separate laser sensors, sonar sensors or an optical recognition.

Next I'm going to look into is open floor management. When an AGV needs to cross large surface like an open factory floor or an open spaced warehouse floor, this tests the AGV's positioning methods. When the area is wide enough and doesn't have any fixed objects like walls, the NN might lost its track of position. The NN's laser measure and optical recognition methods might not get any position data. The laser sensors measurement have distance limit and the measurement is as imprecise as further it needs to measure. Same is with the optical recognition. The cameras might not recognize objects too far away. So the NN is vulnerable in open spaces. The UWB can manage open spaces but it suffers also from the distance. The distance makes the UWB's connection worse, but that's why UWB beacons are planted to several places to cover areas that might have bad connection. Then there is the inductive guidance, the magnet spot and the RFID positioning. They are not affected by open areas, because the fixed hardware is also mounted on the open areas.

Next I'll look into a variety of tasks. I see that performing tasks should not depend on the positioning method. So how many different types' of tasks AGV could perform with these positioning methods? Here I mean by variety that how complex routes and route changes can be performed with a used positioning method. This then means that how flexible the method is. Here table's 2 fixed technologies can't compete to the NN and the UWB. The fixed technologies may have variety routes built for performing different tasks, but still the possibilities are limited. The NN and UWB methods are more flexible than the fixed technologies. The NN and UWB can handle as many different tasks as a higher system can create routes.

Then there is frequency of the tasks. This is meant to show that how well the technologies can perform repeated tasks. All methods can manage to do this, but the fixed methods are the best of doing this. When an AGV is doing a same task multiple times, it is using same routes every time. Then there is no matter, that is the technology movable or not. Still same time the NN and the UWB methods can perform here as fine as the fixed methods.

Next is a communication between other AGVs. When a factory floor or a warehouse floor is filled with AGVs it’s good to have them to communicate with each other, just to avoid collisions and manage optimal path planning. Every handled method can perform this trough higher system, but here only the UWB has possibility to communicate with other UWB AGVs. UWB AGVs may get other AGVs’ a position data through the UWB signals.

After this evaluation I would say that mainly the NN with laser sensors is now the best method to apply to automated heavy-duty vehicles. It has some weak points, but those can be fixed with other technology. When picking just one positioning method, I would choose the NN. Best example from this is chapters 4.1 the Kuka’s OmniMove that navigates with the natural navigation and uses LIDAR laser sensors. Like told the NN makes own map and navigates through it. If the environment is already known, I would prefer that already made map is given to a NN AGV and the AGV would make changes to the map when it detects changes in it.

For example we have an autonomous heavy-duty platform, that does only lifting and moving objects. It would use mainly the natural navigation with LIDAR sensors. It would needs to communicate with other heavy-duty platform AGVs, so it would also have UWB tags to communicate with other vehicles and same time to support positioning data as back up. A back up UWB positioning technology would need separate fixed hardware. When the heavy-duty platform AGV needs to cross an open factory floor, the NN and the UWB might not to manage the crossing. Then to the AGV could be applied own method just for the crossing the open areas. The method could be one of the tables 5 fixed methods.

In the big picture some of these days indoor positioning methods can handle AGV’s positioning by themselves, but some of them need other technologies beside them to do the task. In the future the positioning methods will become more independent from the surroundings and they won’t need any fixed hardware. Same time it makes from the AGV more independent and autonomous. This takes the AGVs closer to humans’ positioning methods and beyond that.

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